AR-008-418

DSTO-TR-0132

Tie-down Trials Involving a Sikorsky S-70B-2 Helicopter

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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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ABSTRACT

Two tie-down trials involving a Sikorsky S-70B-2 helicopter are outlined. The first was land-based and utilised a hydraulic tilt table. The second took place on board an FFG-7 frigate. The trials are part of a DSTO investigation aimed at improving the tie-down procedures of S-70 B-2 helicopters when operating from ships. A preliminary analysis of the data is presented and indicates that the type of lashing used to secure the helicopter can have a significant effect on the loads transmitted to the fuselage as well as affecting the relative motion of the aircraft. The effect of aircraft brakes on or off was examined and found to result in noticeable differences to the aircraft behaviour. During the ship trial, one type of tie-down lashing was observed to suffer from significant slippage through its locking mechanism.

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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Published by

DSTO Aeronautical and Maritime Research Laboratory
PO Box 4331
Melbourne Victoria 3001 Australia

Telephone: (03) 626 7000
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AR No. 008-418
January 1995

APPROVED FOR PUBLIC RELEASE

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EXECUTIVE SUMMARY

The Air Operations Division (AOD) of the Defence Science and Technology Organisation (DSTO) is assisting the Royal Australian Navy (RAN) in developing an improved tie-down scheme for Sikorsky S-70B-2 helicopters on board FFG-7 ships. Possible modifications are in the tie-down configuration (lashing types, tensions, and numbers) and the aircraft configuration (whether brakes should be ON or OFF) and are expected to result in different ship motion limits being defined. When ship motion is greater than these limits, an engineering inspection is required to check for possible damage to the helicopter. The Aircraft Maintenance and Flight Trials Unit (AMAFTU) of the RAN conducted a First of Class Flight Trial (FOCFT) for S-70B-2 on an 'Adelaide' class FFG-7 in March 1994 and this is expected to lead to further modifications to ship motion limits according to operational considerations.

AOD has developed a computer model for the S-70B-2 on a ship deck which includes a detailed representation of the undercarriage. The model includes a capability to represent the helicopter secured by a variable number of lashings. The model, together with trial results, will be used to help develop an improved tie-down scheme. This document details two tie-down trials that have taken place and presents a preliminary analysis of the trial data.

The first trial involved an S-70B-2 tied down on a hydraulic tilt table. A precisely controllable and repeatable environment was created allowing progressive build up to limiting cases. In addition, all instrumentation was able to be fully tested prior to the second trial when time was at a premium. The second trial involved an S-70B-2 tied down in the hangar of HMAS MELBOURNE, an FFG-7 frigate. This trial allowed additional degrees of freedom to be examined, as well as involving additional restraint using the Rapid Securing Device (RSD). Several tie-down variables were examined and preliminary conclusions have been drawn.

Examination of different tie-down lashing types indicated that the loads transmitted to the airframe can be significantly reduced by using extendible webbing as opposed to the chains which are part of the current tie-down scheme. However, the greater extendibility of the webbing allows the helicopter to roll more, which may lead to clearance problems in a ship hangar and difficulties for personnel when conducting maintenance. Lashings of intermediate extendibility were examined by using double thickness webbing.

The trials examined brakes both ON and OFF. Brakes ON, currently part of the standard tie-down procedure, was found to reduce the motion of the helicopter when compared with brakes OFF, but created additional loads on the undercarriage due to the main oleo and drag link geometry. This may be of concern for the extended periods encountered while at sea.

Two types of webbing lashing (MC-1 and CGU-1/B) were examined. The MC-1 lashings were found to slip significantly in their locking mechanisms during ship trials in sea state 4 in spite of loads being significantly below the rated 3000 lbf limit. Most webbing tests on the ship were therefore performed using CGU-1/B lashings, which did not exhibit slippage. During the tilt table trial, when MC-1 lashings were used, no slippage was evident.

The effect of the RSD was examined and, for the short term tie-down procedure using chain lashings at normal tension, it appears that the RSD takes little of the load from the forward tie-down chains, but significant load from the aft tie-down chains. However, higher sea states or use of more extendible webbing lashings, both resulting in additional helicopter motion, may lead to different conclusions.

Further analysis of the data, together with modelling results using the AOD on-deck model, will be reported on at a later date.

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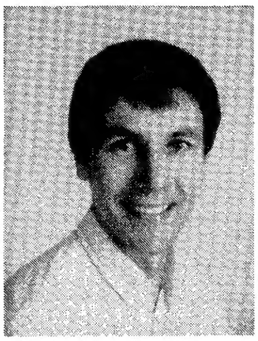

Jeremy Blackwell graduated with first class honours in Mathematics and Physics from the University of Durham, UK in 1982. In 1983 he came to Australia and undertook a PhD in Aeronautical Engineering at the University of NSW, Sydney. He commenced employment at the then Aeronautical Research Laboratory in 1987 as a Research Scientist, and was promoted to Senior Research Scientist in 1994. Jeremy has been involved with mathematical modelling of the dynamics and flight dynamics of helicopters, with particular reference to the helicopter-ship dynamic interface. He has also obtained extensive trials experience, as well as expertise in data processing and the use of such data for model development.

CONTENTS

1. INTRODUCTION

The Air Operations Division (AOD) of the Defence Science and Technology Organisation (DSTO) is assisting the Royal Australian Navy (RAN) in developing an improved tie-down scheme for Sikorsky S-70B-2 helicopters on board FFG-7 ships. Possible modifications are in the tie-down configuration (lashing types, tensions, and numbers) and the aircraft configuration (whether brakes should be ON or OFF) and are expected to result in different ship motion limits being defined. When ship motion is greater than these limits, an engineering inspection is required to check for possible damage to the helicopter. The Aircraft Maintenance and Flight Trials Unit (AMAFTU) of the RAN conducted a First of Class Flight Trial (FOCFT) for S-70B-2 on an 'Adelaide' class FFG-7 in March 1994 and this is expected to lead to further refinements in the tie-down envelope according to operational considerations.

AOD has developed an on-deck model for the S-70B-2 (Ref. 1) which includes a detailed representation of the undercarriage. The model includes a capability to represent the aircraft secured by a variable number of lashings. The model, together with trials initiated by AOD, will be used to help develop an improved tie-down scheme. This document details two tie-down trials that have taken place and presents a preliminary analysis of the trial data. More detailed analysis of the data, comparison of data with model results, any model refinements required, and use of the model to analyse optimum tie-down schemes will be the subject of a further document.

Imperial units are adopted throughout this document because (a) they are used exclusively by workers in the US with whom AOD is collaborating, (b) both the helicopter and ship referred to are built in the US to imperial specifications, and (c) the RAN work in imperial units when dealing with this helicopter and ship.

2. TRIALS

2.1 Outline

Two tie-down trials were required. The first involved an S-70B-2 tied down on a hydraulic tilt table at the Engineering Development Establishment (EDE) proving ground, Monegeetta, Victoria. The table was able to move in only one degree of freedom (corresponding to rolling motion of the helicopter), but created a precisely controllable and repeatable environment and was ideal for trying out non-standard tie-down configurations prior to embarking on a ship. It also allowed progressive build up to limiting cases. In addition, it allowed all instrumentation to be fully tested prior to ship trials when time was at a premium. The second trial involved an S-70B-2 tied down in the hangar of an FFG-7 frigate, HMAS MELBOURNE. This trial was required because it provided an extra five degrees of freedom and was also "the real thing", so covered any eventualities that might have been overlooked during the tilt table trial. In this second trial, the helicopter was secured by the Rapid Securing Device (RSD) in addition to the tie-down lashings for some of the data runs since this is standard RAN practice up to and including sea state 5. The RSD is a device on the ship deck which is able to restrain the aircraft by clamping a probe that protrudes below the fuselage. The RSD allows limited up and down motion of the probe, and allows rotation in the roll and pitch axes. Linear motion of the probe in the directions of the longitudinal and lateral ship axes is precluded by the RSD. A second probe, located in the tail wheel strut of the helicopter, prevents aircraft yaw.

The short term tie-down configuration was used as the basis for each trial. This consists of four lashings, one attached to each of the four S-70B-2 fuselage mounting points (Fig. 1). Load cells were used on each lashing. For the tilt table, since it only tilted one way (port side up), only half of the tie-down scheme (two lashings on the port side) was required. For the ship, all four lashings were used. Reduced numbers of lashings were also examined, with additional safety chains. A brief examination was also made of the intermediate tie-down

scheme, which involves 8 lashings (Fig. 1). The location of the S-70B-2 fuselage tie-down points is shown in Fig. 2 where the station (STA), waterline (WL), and buttline (BL) are in inches.

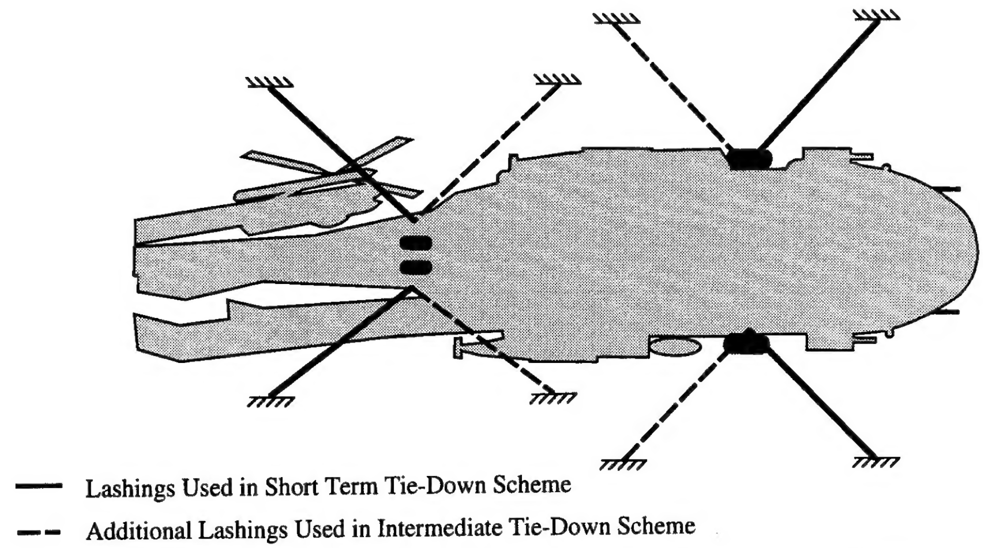

Fig. 1 Short and Intermediate Term Tie-Down Schemes for S-70B-2

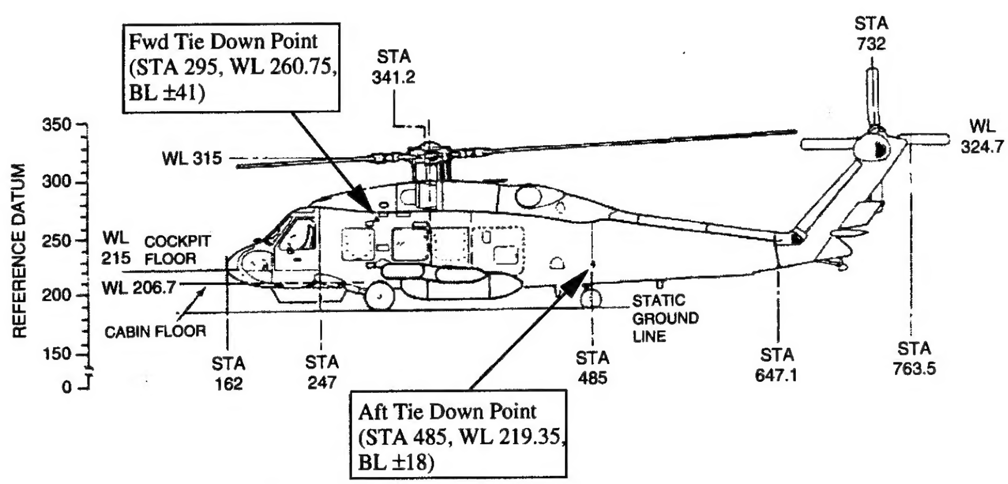

Fig. 2 Fuselage Tie-Down Point Locations on Sikorsky S-70B-2 Helicopter

Different tie-down lashing types were used in the trials to ensure a range of lashing extendibility was examined. These included TD-1A chains (standard aircraft lashings for the S-70B-2 rated at 10000 lbf), MC-1 webbing (standard aircraft lashings for Aerospatiale AS 350B Squirrel helicopters rated at 3000 lbf*), CGU-1/B webbing (cargo† lashings rated at 5000 lbf), and double thickness MC-1 and CGU-1/B. Additional slack TD-1A safety chains were used whenever non-standard S-70B-2 lashings were being used. The safety chains were monitored and observed to occasionally go taut momentarily. Such instances were recorded.

* MC-1 webbing lashings are rated at 5000 lbf in accordance with MIL-T-8652A(ASG), but have been down rated by the RAN for aircraft use to 3000 lbf to allow for operational deterioration of the webbing.

† CGU-1/B webbing lashings are not authorised for use as aircraft tie-down lashings. The authority to use them during the trial on board HMAS MELBOURNE was provided by the RAN Trials Manager, LCDR Mel Schmidt.

Different "at rest" tie-down lashing tensions were examined including the *normal* S-70B-2 tie-down tension where about 1 to 1.5 inch of slack lashing exists*, *increased* tension where lashing lengths were reduced by 1 inch from *normal*, and *reduced* tension where lashing lengths were increased by 1.5 inch from *normal*.

The effect of brakes ON and OFF was also examined. Brakes ON is the standard operating procedure for the S-70B-2 when tied down. However, it soon became apparent during the tilt table trial that brakes ON led to significant differences in aircraft behaviour compared to brakes OFF. These differences were due to the trailing drag link arrangement of the main landing gear combined with the asymmetric loading on the tilt table (see Section 3). Whenever brakes were OFF, wheel chocks were placed around (but not touching) the front wheels as a safety precaution. The distance between wheel and chock was monitored to ensure contact was not made which would distort the tyre and make model comparisons difficult. The tail wheel castor was kept locked throughout both trials, as is standard RAN practice for a helicopter stowed on board ship. Some trial runs were duplicated to check for repeatability.

The helicopter blades and fuselage were in a folded configuration throughout both trials as would occur in a ship hangar.

Instrumentation for the two trials included (i) a motion platform mounted on the tilt table and ship to monitor linear accelerations, attitudes, and angular rates, (ii) Linear Variable Differential Transformers (LVDTs) to monitor aircraft tyre and oleo compressions, (iii) linear potentiometers mounted between fuselage and table/ship to monitor relative displacement of the aircraft and table/ship in all three directions, and (iv) load cells (four) to monitor loads in the tie-down lashings. In addition, aircraft accelerations, attitudes, and angular rates were recorded using on-board instrumentation. For the ship trial, the ship heading and speed were also recorded. The channels recorded in both trials are summarised in tables in Appendices A and B.

Both still and video camera coverage of each trial were made. This included recordings from video cameras mounted to the table and deck to monitor tie-down lashings and record undercarriage movement.

Details specific to each trial are discussed next.

2.2 Tilt Table Trial

The tilt table, which measures 22.24 ft by 11.19 ft, is hydraulically operated. One edge can be raised to give a tilt between 0 deg (horizontal) and an angle up to 60 deg. The rate of tilt was linear and was adjustable. The hinge was on the starboard side of the aircraft. Prior to modification (see below), the tilt table was manually controlled. The helicopter was placed on the table and tied down with two lashings, one at the forward port fuselage tie-down point, and one at the aft port fuselage tie-down point. The table was then raised to different tilt angles and lowered to obtain dynamic data. Tilt table runs were generally of two cycles duration. A number of cases was duplicated to check repeatability. A series of data runs was also made with the table tilt angle held fixed at various angles up to 10 deg while the helicopter tie-down lashings were adjusted to ensure they remained slack. This allowed suitable data to be obtained for determining lateral tyre spring coefficients and helicopter vertical centre of gravity (cg) position.

The following table modifications were performed by the Aeronautical and Maritime Research Laboratory (AMRL) before the trial could take place (see acknowledgments):

(i) Tyre lateral restraining plates were designed and manufactured, one for each main wheel and one for the twin tail wheel, to prevent the helicopter sliding. A gap of about 1.25

* 1 to 1.5 inches of slack equates to a condition where the tie-down hook cannot quite be removed from the eye. This is the methodology currently used by the flight deck training team at RAN Air Station Nowra, New South Wales, Australia. However, it appears that no written guidance is available.

inch was left between tyre and plate so tyre deformation was not affected by the plate during operation unless the wheel slid.

(ii) Two beams that each incorporated a tie-down point were designed and manufactured. Existing tie-down points on the table were in the wrong location when compared to typical FFG-7 hangar tie-down points.

(iii) Two vertical posts were designed and manufactured. They supported the transducers that determined relative position of helicopter fuselage and table. Additional bracing had to be added because of significant vibration of the posts which was induced by the sudden change in direction of the table at the end of each cycle.

(iv) A computer program was developed which, through a potentiometer mounted under the table, was able to control the tilt table angle. The program allowed lower and upper angular limits to be input and then either manual or automatic raising/lowering of the table between these limits. The rate of tilt of the table, which was variable up to 40 deg/min, was only able to be controlled from the table control room.

(v) A safety switch was constructed to cut out power to the table if the angle exceeded a predetermined value (typically around 20 deg).

Structures in (i) and (ii) above were designed using load limits which were determined using the AOD on-deck model for table angles up to 20 deg at the maximum tilt rate. A safety factor of two was then applied, resulting in peak lateral loads (assuming zero tyre friction coefficient) for the restraining plates of 5300 lbf, 9300 lbf, and 7300 lbf for the port, starboard, and tail wheels respectively. Each tie-down point had to be able to take a load of 8700 lbf (including the safety factor of two) along a line from the table tie-down point to the helicopter tie-down point. In addition, a maximum deflection of 0.2 inch was allowed for each tie-down point. This was to occur at the peak tie-down loads but without the factor of safety (i.e. 4350 lbf) since it was not a safety consideration but a way to ensure tie-down lashing lengths were known to within 0.2 inch accuracy. The stress analysis was performed by Facilities and Engineering Services of AMRL using the I-DEAS Finite Element Modelling and Analysis Package (Ref. 2). In addition, a maximum height of 6.5 inch was specified for the beams over which the radome passed when the helicopter was being towed onto the table to ensure adequate clearance. Lateral adjustability of the structure was also allowed because the location of the helicopter on the table was not able to be determined precisely. Existing table lugs and holes were utilised for all attachments so that no drilling of the table was required.

Proof testing of the tie-down beams took place before the helicopter was put on the table. This involved positioning a crane on the table with an adjustable boom. The crane pulled on a cable which was attached to each tie-down point in turn. The boom was moved so that the cable angle duplicated that which would occur when the helicopter was tied down. Loads of 7644 lbf and 7531 lbf were safely maintained for the forward and aft tie-down points respectively.

A plan view of the table is shown in Fig. 3, together with an overlay of the folded S-70B-2.

During raising and lowering of the table, each wheel was monitored to determine whether the tyre bulge made contact with its restraining plate which would affect the tyre distortion. It was found that the main wheels never made contact, but that the twin tail wheel with its softer tyres did make slight contact during some tests at the higher tilt angles. It is anticipated that in these instances, the tyre compression in the direction perpendicular to the table was not significantly affected. However, when results are compared with model predictions at a later date, some account may need to be taken of the additional tyre distortion caused by the restraining plate.

A photo taken during the trial is shown in Fig. 4.

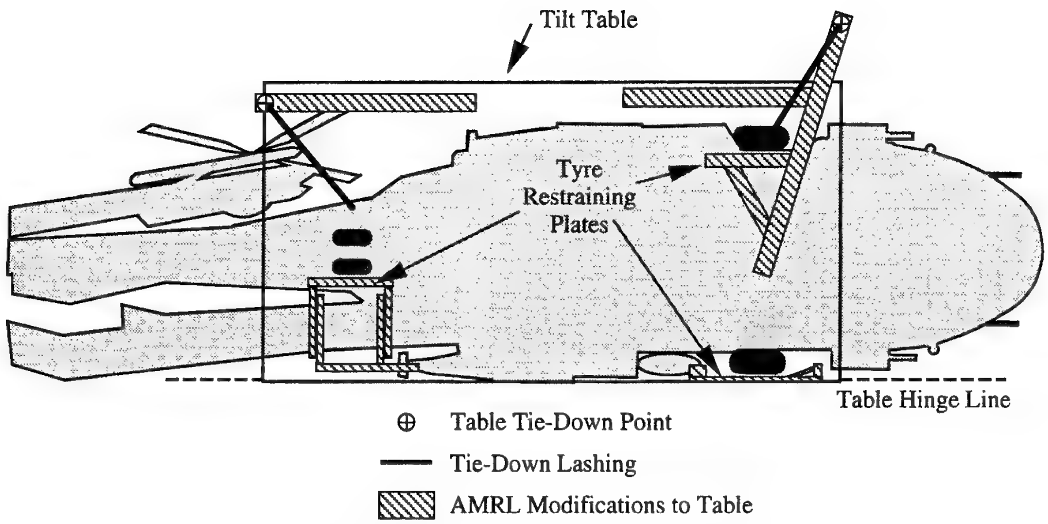

Fig. 3 Plan View of Folded S-70B-2 and Modified Tilt Table Showing Tyre Restraining Plates and Tie-Down Points

Fig. 4 Tilt Table Trial

The trial took place between 11 and 15 October 1993 and followed the plan developed by AOD and approved by Navy (Appendix A) with the following changes:

(i) A few of the tilt table angular limits were reduced slightly from the trial plan as requested by the RAN trials officer, e.g. 18 deg table tilt angle was reduced to 15 deg for item 14.

(ii) Since data quality appeared good after the first few runs, some of the repeatability checks were omitted and not all MC-1 webbing cases were examined.

(iii) Although the trial plan specified brakes ON for all runs, as is standard operating procedure for the S-70B-2 when tied down, it soon became apparent that this restricted main oleo movement significantly. Chocks were placed around the main wheels (with a small clearance to avoid tyre contact) and subsequent tests were performed mainly with brakes OFF, but with a sample of results with brakes ON for comparison purposes.

Whenever brakes were ON, after two cycles had been completed, brakes were released and the settling of the helicopter recorded.

Trial conditions obtained are given in Appendix C.

2.3 Ship Trial

The trial on board HMAS MELBOURNE took place between 24 and 27 October 1993 which included two days to set up instrumentation and 30 hours at sea for the trial itself. The aircraft was stowed in the starboard hangar. Instrumentation was identical to that used in the tilt table trial though the position transducers were mounted on the walls (bulkheads) of the hangar rather than on posts.

A plan of the starboard hangar showing the tie-down points together with an overlay of the folded aircraft is given in Fig. 5. The Recovery Assist, Secure and Traverse (RAST) track, which runs along the deck, is also shown.

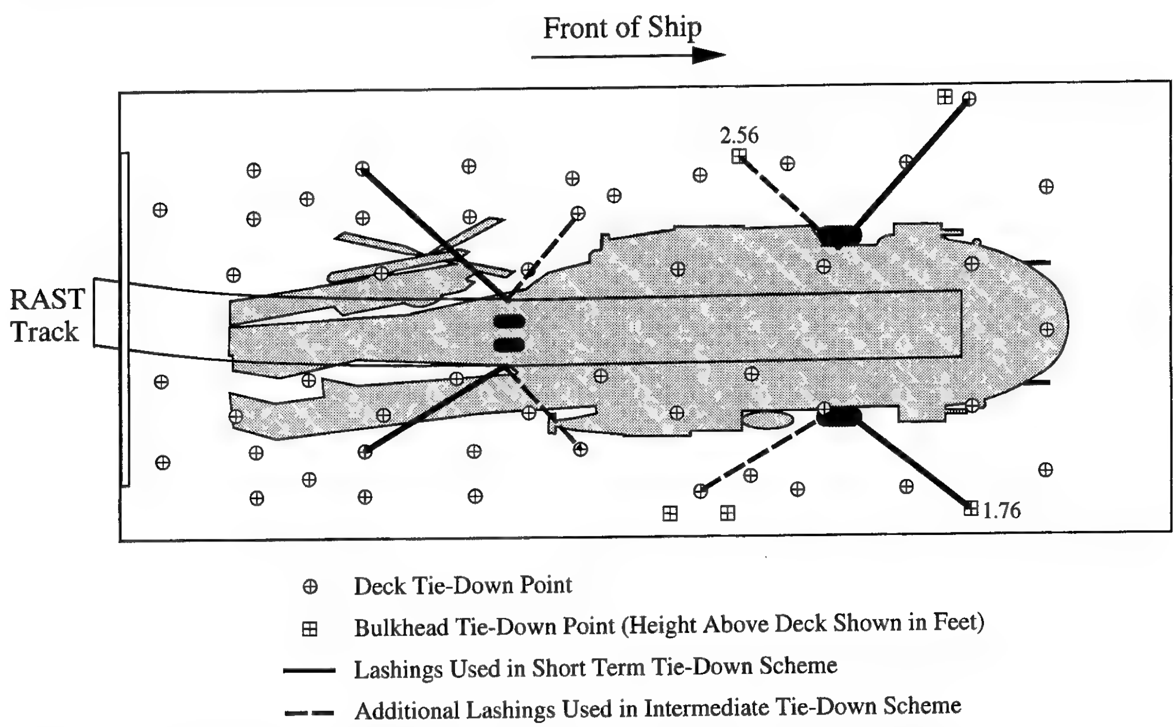

Fig. 5 Plan View of Starboard Hangar on HMAS MELBOURNE Showing Available Tie-Down Points and Those Used During Trial

Sea states ranging from 2 to 4 were encountered during the trial. For a given sea state, the ship speed and heading were altered to provide three distinct ship motions; predominantly rolling motion, predominantly pitching motion, and a mixture of roll and pitch. Due to time limitations, it was not possible to obtain each ship motion for each tie-down configuration. Trial conditions obtained are summarised in Table 1 and are given in more detail in Appendix D. From an operational point of view, it was easier to alter the tie-down configuration while the ship maintained its speed and heading, and this explains the layout of results in Appendix D. Data runs (consisting of a single tie-down configuration with ship speed and heading held constant) were of 5 minutes duration.

The RSD was engaged for most of the data runs, though a selection of data was obtained with the RSD disengaged for comparison purposes. The RSD was only disengaged when the ship motion was not excessive so that there was unlikely to be a problem realigning the RSD probe afterwards.

The trial followed the plan developed by AOD and approved by Navy (Appendix B) with the following modifications:

(i) MC-1 webbing lashings were replaced by CGU-1/B webbing lashings due to slippage (Section 3.2).

(ii) For the RSD connected, tests using reduced tension webbing (items 17 and 18) were not performed due to the lack of restraint they provided in the limited confines of the hangar brought about by the relatively high ship motion (sea state 4). The normal tension component of the reduced number of webbing lashings (item 14) was not covered for similar reasons.

(iii) With the RSD disconnected, several cases were not covered because of the reasonably high amplitude ship motion (sea state 3). These included no lashings (item 22), normal and reduced tension webbing lashings (items 23 and 27), and reduced number of lashings (items 29 and 30).

(iv) Due to time constraints, up to three ship motions were covered for each trial plan item rather than the four referred to in the plan. These were (a) ship rolling motion dominant, (b) ship pitching motion dominant, and (c) a mixture of pitch and roll.

Also, in response to a late RAN request, a brief examination was made of the intermediate tie-down scheme involving eight tie-down lashings (Fig. 5) using chains at normal tension, brakes ON and OFF, and with load cells on one side of the aircraft only since only four were available.

TABLE 1
Summary of Test Conditions Achieved during Ship Trial

RSD Status	Tie-Down Lashing Type	Ship Motion	Reference Table (Appendix D)
Connected	TD-1A Chains	Roll & Pitch both Significant	D1
Connected	TD-1A Chains	Roll Dominant	D2
Connected	MC-1 Webbing	Roll & Pitch both Significant	D3
Connected	CGU-1/B Webbing	Roll & Pitch both Significant	D4
Connected	CGU-1/B Webbing	Pitch Dominant	D5
Disconnected	TD-1A Chains	Roll Dominant	D6
Disconnected	CGU-1/B Webbing	Roll Dominant	D7
Disconnected	TD-1A Chains	Roll & Pitch both Significant	D8
Disconnected	CGU-1/B Webbing	Roll & Pitch both Significant	D9

3. RESULTS AND DISCUSSION

Tilt table runs were generally of two cycles duration. Ship data runs were of 5 minutes duration to allow for several cycles of ship motion. A total of 40 data runs was performed on the tilt table and 62 runs for the ship using a variety of tie-down configurations with brakes both ON and OFF. A summary of the test conditions achieved is given in Appendix C for the tilt table trial, and Appendix D for the ship trial. A sample of results is presented below and a few conclusions drawn. It should be noted that comparison between different tie-down configurations is significantly easier for tilt table data than for ship data since duplication of trial conditions is possible due to the repeatability of the tilt table motion. For the ship, no two runs exhibited identical ship motion and any comparison requires statistical analysis. A brief examination is made of the effect of the RSD (Section 3.4) where ship data have been used out of necessity.

3.1 Effect of Lashing Type

Fig. 6 shows tilt table results for a maximum tilt angle of 15 deg for helicopter brakes OFF (files 11, 25, and 35 in Appendix C). The figure shows (a) tilt table angle, (b) helicopter roll

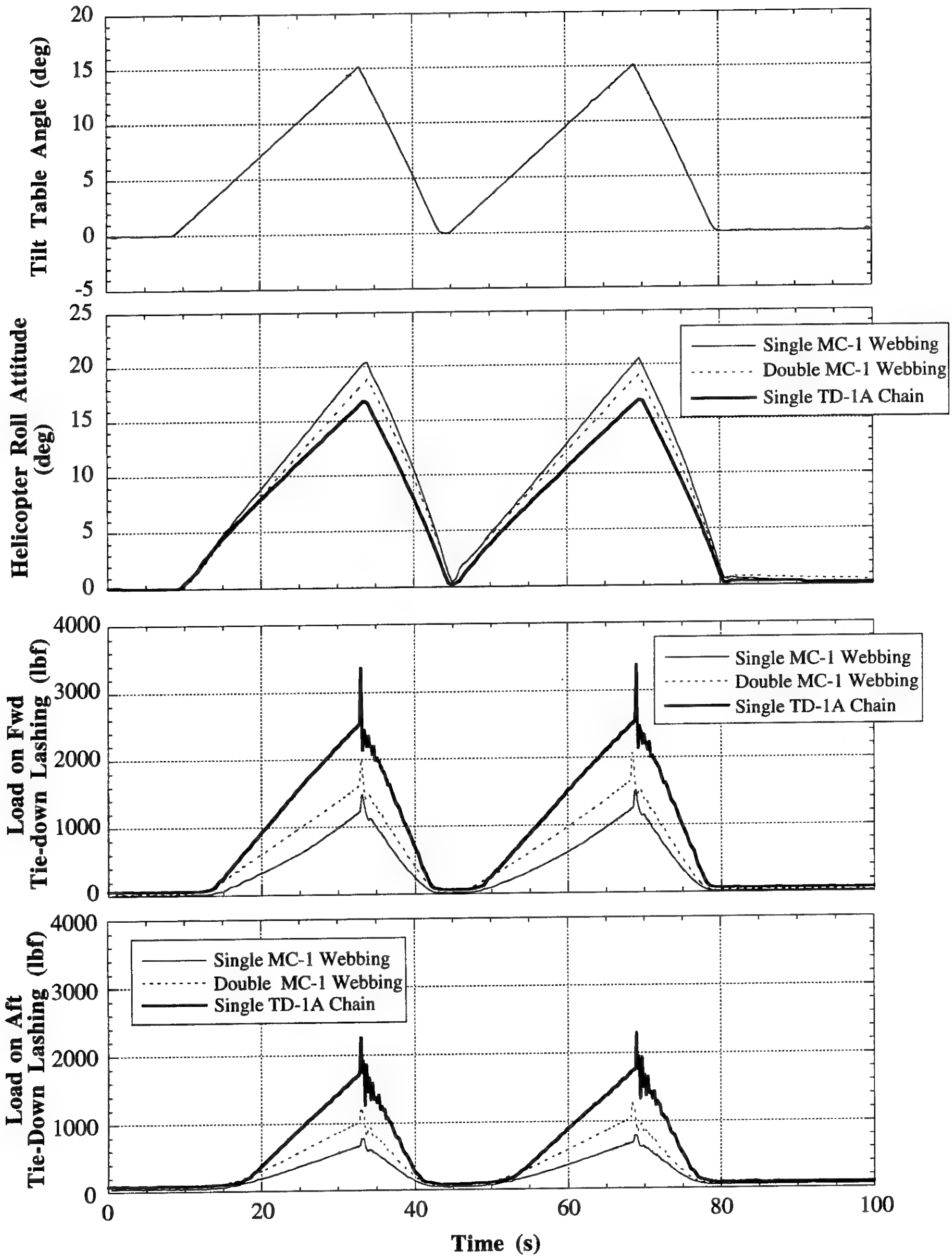

Fig. 6 Roll Attitude and Tie-Down Loads for S-70B-2 on Tilt Table Using Different Lashing Types (Normal Tension, Brakes OFF)

attitude, (c) load on forward tie-down lashing, and (d) load on aft tie-down lashing. Results are shown for three different lashing types; single MC-1 webbing, double MC-1 webbing, and TD-1A chain, all at normal tension. It is apparent from (c) and (d) that the quasi-steady load on the airframe is reduced considerably by using extendible webbing as opposed to the standard TD-1A chains. However, (b) shows that this is at the expense of greater helicopter roll attitude. An extra 3.6 deg of roll occurred when using single thickness MC-1 lashings compared to the TD-1A chains. This would lead to reduced clearance in the narrow confines of a ship hangar, and may be of concern. In addition to the quasi-steady loads being highly dependant on the extendibility of the lashings, the transient loads caused by the table suddenly changing direction are also reduced significantly by using webbing instead of chains. For instance, a transient load of 830 lbf occurred in the forward TD-1A chain compared to a transient load of only 250 lbf for the single thickness forward MC-1 lashing.

3.2 Effect of Brakes ON or OFF

The trailing drag link arrangement of the S-70B-2 main oleos (Fig. 7) means that, as each main oleo extends, the attached main wheel moves forward relative to the fuselage. Thus if the helicopter roll attitude changes with respect to the floor, one of the main wheels has a tendency to move forward relative to the other one. If brakes are OFF, then the wheels are able to roll to balance longitudinal forces, and the oleos can extend or compress freely. However, for brakes ON, the wheels cannot roll and the excessive loads create deformation or sliding of the tyre, and the oleos are prevented from extending or compressing freely. The effect is enhanced on the tilt table which tilts in only one direction and allows a differential in oleo compression between the main gears to build up over several tilt cycles as follows: At high tilt table angles,

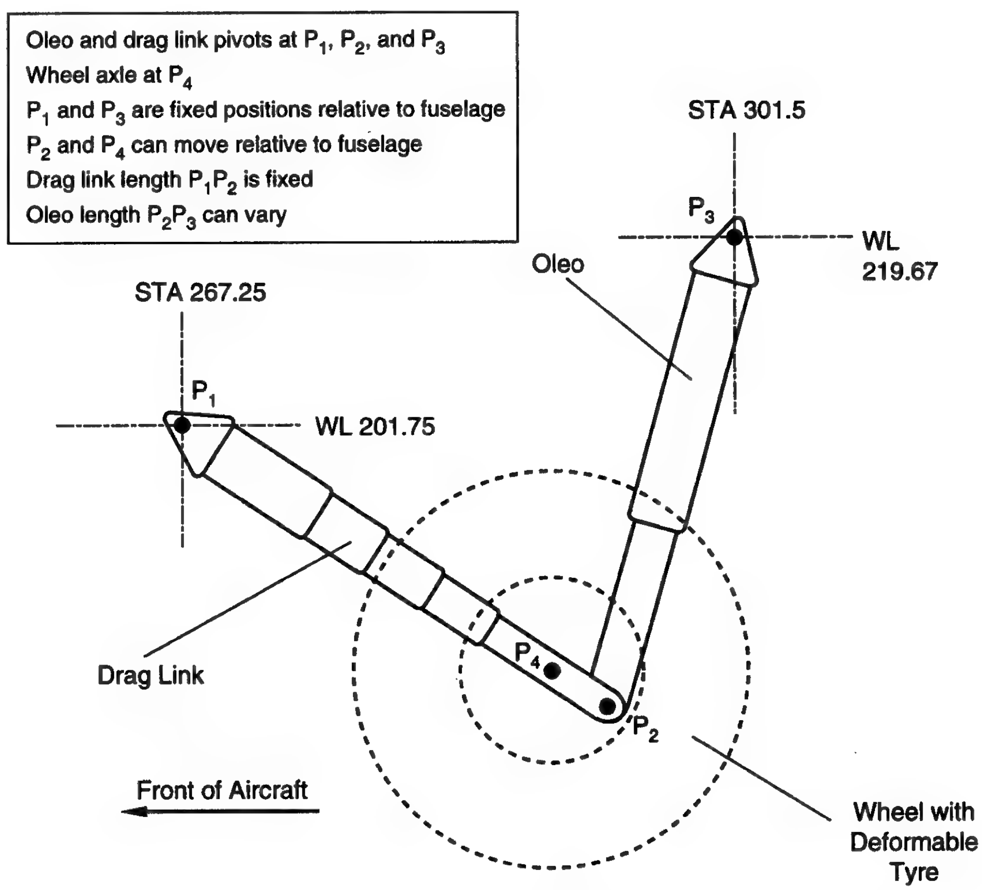

Fig. 7 S-70B-2 Main Oleo and Drag Link Arrangement

the port wheel becomes very lightly loaded and the reduced friction allows the port tyre to slide forward even when brakes are ON. As the table is then lowered, the wheel has a tendency to move back, but increased load and hence increased friction force prevent the wheel from sliding, and the oleo is unable to compress back to its original position creating a differential in oleo compression between port and starboard gears. This differential increases over successive cycles. The effect is illustrated in Fig. 8, which shows tilt table results for a maximum tilt angle of 12 deg for the helicopter tied down with two double thickness MC-1 lashings with brakes ON and OFF (files 33 and 38 in Appendix C). For brakes OFF, both oleos return to almost the same compression at the end of each cycle.* However, for brakes ON, the port oleo

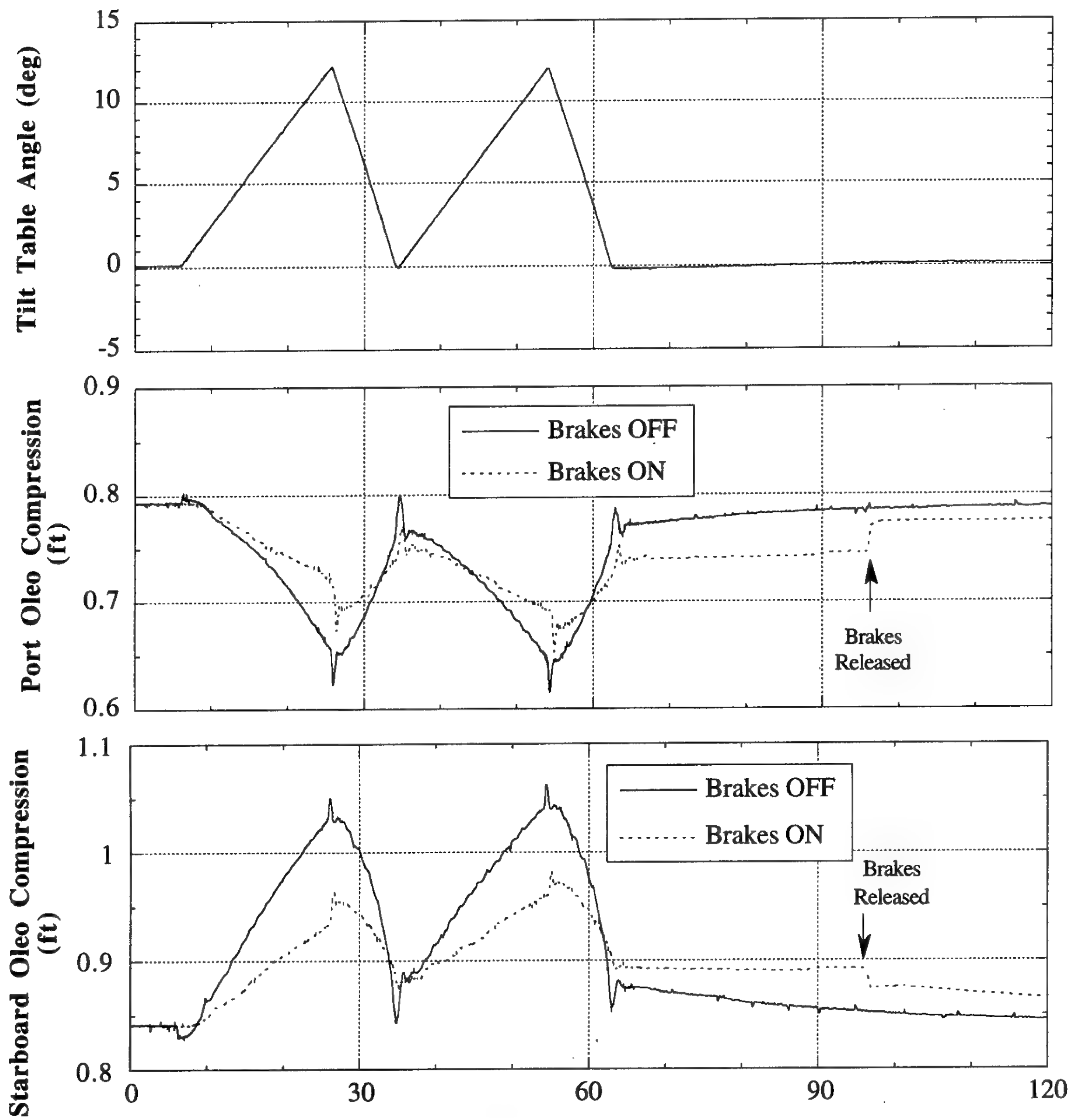

Fig. 8 Tilt Table Attitude and Helicopter Oleo Compressions for Brakes ON and OFF

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* The oleos do not return to quite the same compression after each cycle because the 'sticky' nature of the oleos means that settling is not instantaneous. For brakes OFF, the oleos were still settling almost 60 seconds after the table motion had ceased.

returns to a lower compression at the end of each cycle while the starboard oleo returns to a higher compression for the reasons stated above. The additional compressions built up during two cycles are revealed when the brakes are released. In addition, the amount of main oleo compression caused by the tilting of the table is reduced with brakes ON. For the helicopter on board ship, these effects are less apparent because the ship rolls both ways. However, it does lead to questions as to whether brakes should be ON or OFF when at sea. Clearly, brakes ON reduces longitudinal motion of the helicopter, and is likely to reduce lateral and vertical motion by restricting main oleo movement as discussed above. However, this may be at the expense of excessive longitudinal loads on oleos and tyres. Data were gathered for both brakes ON and OFF and further examination is required before conclusions can be reached.

3.3 Lashing Slippage

During the ship trial, it was found that all MC-1 webbing lashings slipped significantly in their locking mechanisms. Results (Fig. 9) were recorded over a 20 minute period for the helicopter secured by four MC-1 lashings which were initially taut, and with the ship rolling and pitching (Table 1). Note that the forward lashings slipped more than the aft lashings, consistent with their greater loading as found on the tilt table (Fig. 6). Starboard lashings slipped more than port lashings because the ship was listing to port while these results were being taken, which creates greater loads in the starboard lashings. No slippage was recorded during the tilt table trial for MC-1 lashings. Once the problem was noted, webbing tests for the ship trial were performed using CGU-1/B webbing lashings, which did not suffer from slippage but whose lengths were more difficult to adjust. The adjusting and locking mechanisms of the MC-1 and CGU-1/B lashings differed significantly which gives an indication of why slippage occurred for MC-1 but not for CGU-1/B. The CGU-1/B has a ratchet mechanism which is initially released to allow the lashing to be set at a length slightly greater than required. The ratchet mechanism is then used to shorten the lashing to the desired

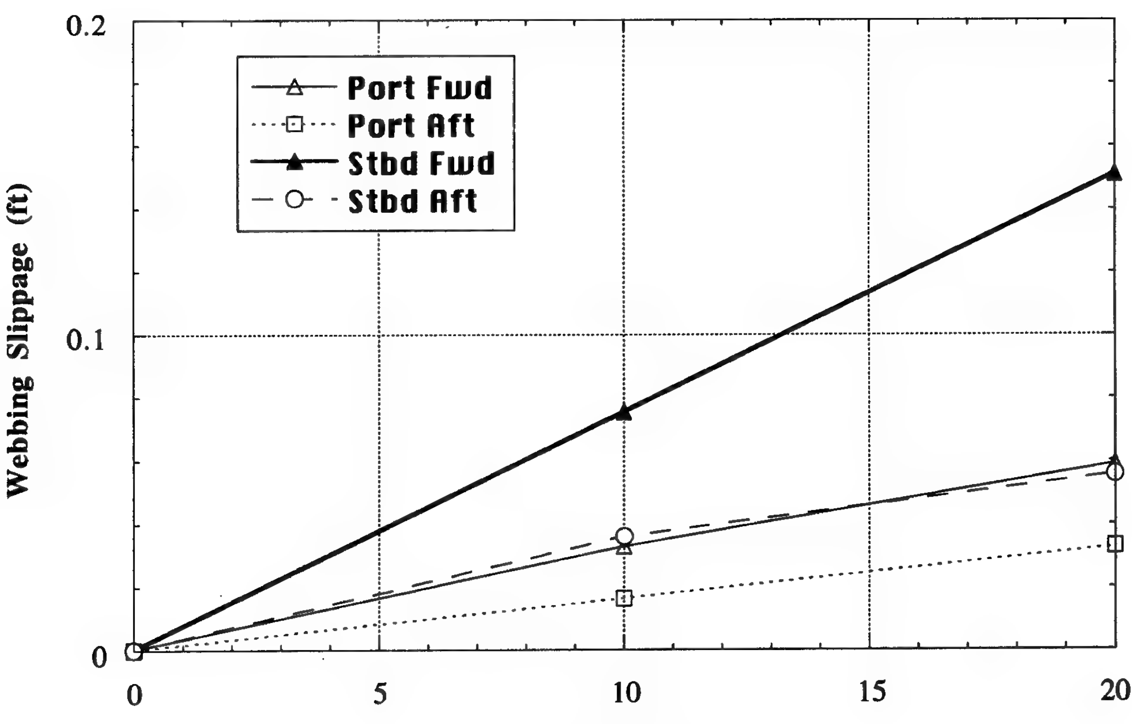

Fig. 9 Slippage of MC-1 Lashings for Helicopter Tied Down on Ship in Sea State 4

length by winding the webbing material around itself. There is a large overlap of webbing and slippage is unlikely. In contrast, the MC-1 has no ratchet system. The webbing is routed through a locking mechanism in an 'S' fashion. The lashing is set to the desired length and tightened by closing the locking mechanism which is restrained from opening by a locking pin. There is minimal overlap of webbing material and a greater likelihood of slippage than for the CGU-1/B.

3.4 Effect of Rapid Securing Device

The effect of the RSD on tie-down loads was examined for the helicopter tied down on the ship by four chain lashings at normal tension. The sea state was 3 and ship roll motion was dominant (files 16 and 49 in Appendix D for the RSD connected and disconnected respectively). Results are shown in Fig. 10 with statistical properties summarised in Table 2. Results for chain load are given for starboard chains only; since the ship was listing to port, there were minimal loads in the port chains. Results show that when measurements were taken with the RSD connected, the ship was listing a further 1.9 deg to port compared to when data were gathered for the RSD disconnected. The standard deviations of the motion were similar for both cases, indicating similar ship motion about a different mean. This makes comparison of tie-down loads more difficult than on the tilt table.

TABLE 2

Roll Attitude and Tie-Down Loads for Ship Trial at Sea State 3 with Ship Roll Motion Dominant

	RSD Connected		RSD Disconnected		
	Mean	Standard Deviation	Mean (Uncorrected)	Mean (Corrected)	Standard Deviation
Ship Roll Attitude (deg)	-3.7	1.8	-1.8	-3.7	1.8
Helicopter Roll Attitude (deg)	-3.9	2.4	-1.8	-4.0	2.5
Load on Forward Stbd Tie Down Chain (lbf)	495	643	147	464	221
Load on Aft Stbd Tie-Down Chain (lbf)	291	443	187	402	222

The helicopter motion is about a similar mean to the ship motion but with larger standard deviation, reflecting greater peak to peak roll attitude due to the compression of the oleos and tyres. Loads on the forward tie-down chains are greater than on aft chains, as determined on the tilt table (Section 3.1). By examining forward or aft chains and comparing RSD connected with RSD disconnected, it appears that greater chain loads occur with the RSD connected. However, the extra 1.9 deg of mean ship roll angle needs to be allowed for. From Figs 6a and 6b for chains at normal tension, the helicopter roll attitude changes approximately linearly at the rate of 17 deg per 15 deg of table angle. The additional 1.9 deg of ship roll is therefore expected to result in about 2.2 deg additional helicopter roll. Also, from Figs 6a, 6c, and 6d, the load on each tie-down chain is seen to change approximately linearly with respect to tilt table angle. For chains at normal tension the rate of change is about 1700 lbf per 15 deg table angle for the aft chain and 2500 lbf per 15 deg table angle for forward chain. This results in corrections of 215 lbf and 317 lbf for the aft and forward chains respectively for an additional tilt angle of 1.9 deg. Corrections are incorporated in Table 2 and are seen to result in fairly similar mean chain loads for RSD connected or disconnected for the forward chain (within 7%), and a load that is 38% higher for the aft chain when the RSD is disconnected. It is concluded from this brief examination that, when tie-down chains are used, the RSD connection does not appear to affect loads on the forward tie-down lashings, but reduces loads on the aft tie-down lashings significantly for sea states up to and including 3. For greater sea states or for more extendible tie-down lashings, where the additional helicopter motion may allow the RSD to play a more significant part, this conclusion may not apply.

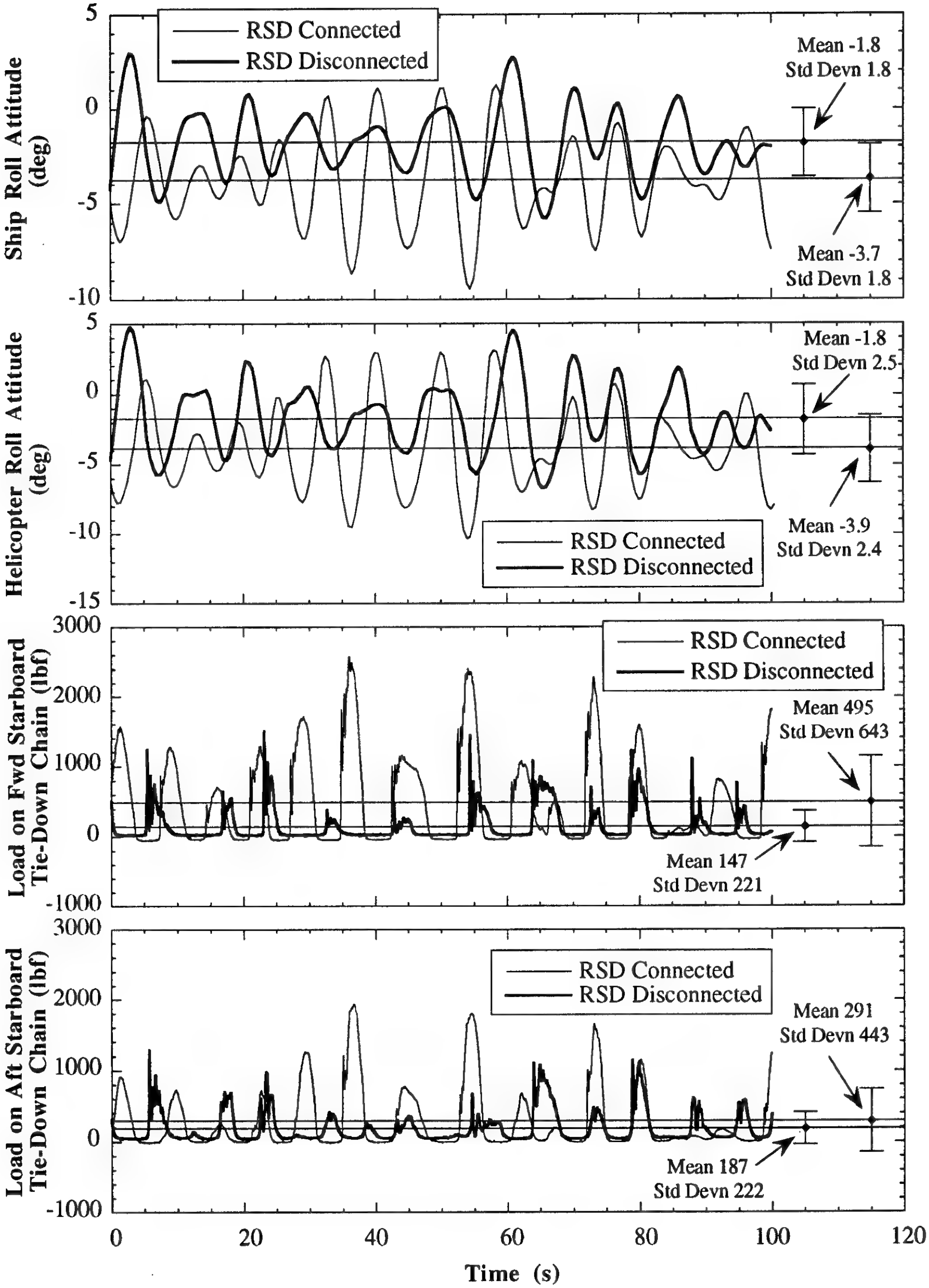

Fig. 10 Roll Attitude and Tie-Down Loads for S-70B-2 on HMAS MELBOURNE in Sea State 3 (Normal Tension, Brakes OFF)

4. CONCLUSIONS

Two tie-down trials involving a Sikorsky S-70B-2 helicopter have been successfully completed. The first involved an S-70B-2 tied down on a hydraulic tilt table. A precisely controllable and repeatable environment was created allowing progressive build up to limiting cases. In addition, all instrumentation was able to be fully tested prior to the second trial when time was at a premium. The second trial involved an S-70B-2 tied down in the hangar of HMAS MELBOURNE, an FFG-7 frigate. This trial allowed additional degrees of freedom to be examined, as well as involving additional restraint using the RSD. Several tie-down variables were examined and preliminary conclusions have been drawn.

Examination of different tie-down lashing types indicated that the loads transmitted to the airframe, both quasi-steady and transient, can be significantly reduced by using extendible webbing as opposed to the chains which are part of the current tie-down scheme. However, the greater extendibility of the webbing allows the helicopter to roll more, which may lead to clearance problems in a ship hangar and difficulties for personnel when conducting maintenance.

The trials examined brakes both ON and OFF. Brakes ON, currently part of the standard tie-down procedure, was found to reduce the motion of the helicopter when compared with brakes OFF, but created additional loads on the undercarriage due to the main oleo and drag link geometry. This may be of concern for the extended periods encountered while at sea.

Two types of webbing lashing (MC-1 and CGU-1/B) were examined. The MC-1 lashings were found to slip significantly in their locking mechanisms during ship trials in sea state 4 in spite of loads being significantly below the rated 3000 lbf limit. Most webbing tests on the ship were therefore performed using CGU-1/B lashings, which did not exhibit slippage. During the tilt table trial, when MC-1 lashings were used, no slippage was evident.

The effect of the RSD was examined and, for the short term tie-down procedure using chain lashings at normal tension, it appears that the RSD takes little of the load from the forward tie-down chains, but significant load from the aft tie-down chains. However, higher sea states or use of more extendible webbing lashings, both resulting in additional helicopter motion, may lead to different conclusions.

Further analysis of the data, together with modelling results using the AOD on-deck model, will be reported on at a later date.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of Fred Bird, Ian Kerton, Dennis Hourigan, and Owen Holland for providing considerable time and effort in developing much of the instrumentation and software for the trials, as well as setting up and monitoring equipment during the trials. Facilities and Engineering Services of AMRL are also acknowledged for designing and constructing the necessary modifications to the tilt table given the trial requirements. This included performing stress analysis calculations. Special thanks are extended to the Engineering Development Establishment (EDE) for making available their hydraulic tilt table and providing technical assistance whenever required. Finally, the cooperation of the Naval Aircraft Logistics Office (NALO), and the Aircraft Maintenance and Flight Trials Unit (AMAFTU) was essential in allowing the trials to proceed as smoothly as they did.

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2. "I-DEAS Finite Element Modelling User's Guide," Structural Dynamics Research Corporation, Ohio, USA, 1990.

APPENDIX A
NAVY-APPROVED TRIAL PLAN FOR S-70B-2 ON TILT TABLE TRIAL

The following trial plan, developed by AOD, was approved by the Naval Aircraft Logistics Office. Footnotes in *italics* have been added since the plan was approved.

Seahawk* Tilt Table Trial at Monegeetta
TRIAL PLAN
27 September 1993

It is planned to position a Seahawk helicopter on a hydraulic tilt table at EDE proving ground, Monegeetta, Victoria during the week 11-15 Oct 1993. The hinge side of the table will be on the starboard side of the helicopter. The table will be raised to different tilt angles and lowered. A variety of tie-down configurations will be used. Some runs will be performed twice to test for repeatability. Aircraft brakes will be on throughout the trial. Instrumentation will record the aircraft motion, tie-down cable† loads, undercarriage compressions, helicopter position, and tilt table motion. The helicopter will be in a folded configuration throughout the trial. It is planned to test all instrumentation and tilt table modifications prior to the trial during a mock trial with a 12 tonne Mack truck tied down on the table during the week 28 Sep - 1 Oct. Instrumentation will be calibrated prior to the mock trial, with the exception of offsets in the position transducers and oleo/tyre LVDTs. The helicopter is to remain on the tilt table each night to avoid having to reposition the aircraft or adjust tie-down cable lengths the following day.

PRIOR TO AIRCRAFT LEAVING RANAS NOWRA

1. The aircraft will be weighed in a folded configuration to allow determination of gross weight and cg position. Allowance will be made for fuel usage en-route to Monegeetta.
2. The aircraft oleo and tyre pressures will be checked and if necessary adjusted.

MONDAY

3a. (or previous Friday) Fit outrigger with main tie-down point and port wheel restraining plate to table *(ARL@ to design and build equipment, EDE to supply crane if required).*

3b. Helicopter arrives pre noon. Fold aircraft.

4. Remove hanging lights from roof if required. Aircraft towed into building and onto tilt table. Care is required due to small doorway and accurate positioning necessary of helicopter on table. Clearance between radome and main tie-down point outrigger is expected to be small while aircraft is being towed onto table. Additional ballast at rear of aircraft may be required during this phase. When on table, port main wheel should be approx half way along the safety plate and have a clearance of 1 to 2 inch between safety plate. Driver and tow motor to be on standby for duration of trial since any sliding of helicopter during a trial run will require correcting prior to next trial run *(tow motor, towing arm, and driver to be provided by Navy).*

5a. Fit remaining two tyre safety restraining plates to table, one on hinge side of each starboard wheel and one on hinge side of twin tail wheel. Allow clearance of 1 to 2 inch between tyre and safety plate so tyre deformation is not affected by contact with plate. Fit beam with modified tail tie-down point to table. Fit two position transducer mounting posts *(ARL to design and build safety plates).*

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* *The term "Seahawk" refers here to the Australian version known as the S-70B-2.*

† *The term "tie down cable" has been superseded in the text of this report by "tie-down lashing" which is a more appropriate descriptor for chains and webbing.*

@ *Aeronautical Research Laboratory, now known as the Aeronautical and Maritime Reseach Laboratory, which is part of DSTO.*

5b. Fit wheel and oleo LVDTs to aircraft (RAN to provide special tool required to attach tail oleo LVDT).

TUESDAY

6. Set up instrumentation (Annex A) including securely attaching motion platform to tilt table and connecting position transducers between aircraft fuselage and posts or table. Synchronise the table and aircraft computers.

7. Perform test run of instrumentation and determine offsets in position transducers and tyre/oleo LVDTs.

8. Attach two tie-down chains with load cells to port side of aircraft (away from table hinge). These chains will be attached at all times when the table is raised. For trial runs where no cable support is desired or when webbing (one of type MC-1 or CGU-1/B) is used in place of chains, the chains will be slackened off and used as additional safety devices. In these instances, load cell readings will be used to check safety chains do not come under tension *(chains, shackles, hooks, and webbing to be provided by Navy).*

9. Helicopter main wheel brakes to be ON for all raising and lowering of table.

10. Perform test raising of tilt table at a low speed (10 deg/minute) up to 12 deg tilt angle. Ensure chains remain unloaded at all times. If necessary adjust chain length.

11a. Raise table to 12 deg at maximum rate (40 deg/minute) and when 12 deg is reached quickly reverse direction and lower table. Check chains remain unloaded throughout transition period. Slight lengthening of chains may be required. Mark chain length.

11b. Perform calibration check of aircraft channels (namely lateral and vertical accelerometers, and roll rate gyro).

WEDNESDAY

TRIAL

12. NO CHAINS IN LOADED STATE

Raise/lower/raise/lower table at maximum rate (40 deg/minute) with minimal reversal time
i) between zero and 6 deg
ii) between zero and 12 deg.

In addition raise table to 4, 8, and 12 deg. Hold at each angle and record data for a few seconds. Also record lateral tyre deformation for each wheel at each angle.

13. REPEATABILITY CHECK

Repeat 12 i) and ii).

14. CHAINS - NORMAL TENSION

Tighten chains such that 1 to 1.5 inches of slack exist* when table is at rest in a horizontal position. Mark chain length. Raise table slowly to 18 deg and check suitable clearance exists between helicopter and roof fittings. Remove roof fittings if required. Then raise/lower/raise/lower table at maximum rate (40 deg/minute) with minimal reversal time
i) between zero and 12 deg
ii) between zero and 18 deg.

15. REPEATABILITY CHECK

Repeat 14.

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* 1 to 1.5 inches of slack equates to a condition where the tie-down hook cannot quite be removed from the eye. This is the methodology currently used by the flight deck training team at RANAS Nowra. However, no written guidance was able to be provided.

16. CHAINS - INCREASED TENSION

Reduce each chain length by 2 inches (or as appropriate) when table is at rest in a horizontal position (some experimentation with precise reduction in length may be required). Raise/lower/raise/lower table at maximum rate (40 deg/minute) with minimal reversal time

i) between zero and 12 deg
ii) between zero and 18 deg.

17. CHAINS - REDUCED TENSION

Increase each chain length by 2 inches (or as appropriate) from the value determined in 14 when table is at rest in a horizontal position (some experimentation with precise increase in length may be required). Raise/lower/raise/lower table at maximum rate (40 deg/minute) with minimal reversal time

i) between zero and 12 deg
ii) between zero and 18 deg.

CHAINS - REDUCED NUMBERS UNDER TENSION

18. Slacken off tail chain to value determined in 11. Adjust length of main chain so that it is at the *normal* tension value defined in 14. Raise/lower/raise/lower table at maximum rate (40 deg/minute) with minimal reversal time

i) between zero and 6 deg
ii) between zero and 12 deg.

19. Slacken off main chain to value determined in 11. Adjust length of tail chain so that it is at the *normal* tension value defined in 14. Raise/lower/raise/lower table at maximum rate (40 deg/minute) with minimal reversal time

i) between zero and 6 deg
ii) between zero and 12 deg.

THURSDAY

WEBBING

20a. Slacken chains off to value determined in 11. Attach two tie-down webbing cables (type MC-1 or CGU-1/B) with load cells to port side of aircraft. Repeat 14, 16, 17, 18, 19. Ensure chains are unloaded throughout. If any loading of chains occurs, lengthen chains slightly and repeat.

20b. Attach two double thickness tie-down webbing cables (type MC-1 or CGU-1/B) with load cells to port side of aircraft. Repeat 14, 16, 17, 18, 19. Ensure chains are unloaded throughout. If any loading of chains occurs, lengthen chains slightly and repeat.

21. Dismantle equipment.

22. Tow helicopter outside and unfold (spread).

23. Helicopter departs pm Thursday or am Friday.

24. ARL to retain one chain and one webbing sample (for a limited period) so a stress-strain relationship can be determined from laboratory measurements.

ADDITIONAL INFORMATION

Aircraft will need to be powered up for each trial run to enable operation of aircraft gyros which are to be recorded *(portable power generator to be provided by Navy).*

Flight crew will not be required from pm Monday until pm Thursday. Due to remoteness of Monegeetta (approx 1 hour from Melbourne), transport would need to be provided.

RAN liaison officer (Lt Mel Schmidt) plus one RAN aircraft handler required for duration of trial. ARL transport can be made available daily to and from the city *(RAN to provide accommodation).*

There is no permanent night guard at Monegeetta *(RAN to organise helicopter security at night).*

Annex A to Appendix A - Channels Required

Aircraft

Variable	Number of Channels	Additional Information
Pitch Attitude Roll Attitude Yaw Attitude Pitch Rate Roll Rate Yaw Rate	1 2 3 4 5 6	Tap off Aircraft (as Planned during Seahawk/FFG-7 FOCFT)
Lateral Acceleration Longitudinal Acceleration Vertical Acceleration	7 8 9	Tap off Aircraft or Use Independent Accelerometers
Port Oleo LVDT Stbd Oleo LVDT Tail Oleo LVDT Port Tyre LVDT Stbd Tyre LVDT Tail Tyre LVDT	10 11 12 13 14 15	Previously Instrumented
Helicopter Position Relative to a Datum* Tie-Down Cable Tensions†	16,17,18,19 20,21,22,23	Not Previously Instrumented

Tilt Table

Variable	Number of Channels	Additional Information
Roll Attitude (Vert Gyro) Roll Rate Lateral Acceleration Vertical Acceleration Pitch Attitude (Vert Gyro)# Pitch Rate# Yaw Rate# Longitudinal Acceleration#	1 2 3 4 5 6 7 8	Motion Platform

- All channels sampled at 40 Hz except load cells which are sampled at 80 Hz.
- Motion Platform to be attached securely to tilt table.
- Two video cameras to be attached securely to tilt table to record starboard and tail tyre compressions. Third video camera to be mounted off table and record table motion and tie-down cable dynamics.

* 3 spring loaded rotary pots with cables, each capable of 1 metre extension, will be used to connect the aircraft fuselage to posts mounted on the tilt table. They will record longitudinal and lateral helicopter position with redundancy. A 4th rotary pot, capable of 0.5 metre extension, will be mounted vertically between helicopter fuselage and table.

† Up to four strain-gauged links will be used, one for each tie-down cable. Maximum load recordable is 2000 kgf.

These variables should give zero readings if instruments are correctly aligned. However, since they are easily included as part of the standard motion platform fit, they should be included, at least for verification purposes.

APPENDIX B

NAVY-APPROVED TRIAL PLAN FOR S-70B-2 ON HMAS MELBOURNE

The following trial plan, developed by AOD, was approved by the Naval Aircraft Logistics Office. Footnotes in *italics* have been added since the plan was approved.

Seahawk* Tie-Down Trial on HMAS MELBOURNE
TRIAL PLAN
20 October 1993

Ref A: Notification of Trials Tasking, ANR 714-41-003, Minute from NALO to AMAFTU, 28 Sep 1993

It is planned to record measurements of a Seahawk in the hangar of HMAS MELBOURNE on Tuesday 26 Oct 1993 and Wednesday 27 Oct 1993 finishing about midday on the Wednesday. The aircraft and ship will then be deinstrumented by mid afternoon when the trials team can depart.

A variety of tie-down configurations will be used. No more than four cables are to be loaded when recording data, but additional slack cables are suggested as a safety measure. However they must be slack enough to ensure they stay unloaded as the ship moves.

Most measurements will be made with the RSD probe engaged, though it is considered essential to obtain some measurements with the RSD probe disengaged for comparison purposes. Measurements with the RSD probe disengaged can take place at lower sea states where there is unlikely to be a problem re-engaging the probe afterwards (see below).

Aircraft brakes will be off throughout most of the trial, since experience in the recent tilt-table trial has shown this to be a preferable configuration. Loose chocks on the main wheels will be required as a safety measure. For cases where brakes are off with the RSD disconnected, someone will be required in the aircraft to operate the brakes if required. A sample of runs with brakes on will also be obtained for comparison purposes.

Instrumentation will record the aircraft motion, tie-down cable loads, undercarriage compressions, helicopter position, and ship motion (Annex A). It is planned to fly the aircraft onto the ship on the afternoon of Friday 22 Oct 1993, fit instrumentation and perform calibrations where required during the following Sunday and Monday, and be ready for an early start on Tuesday 26 Oct 1993. Much of the instrumentation will be calibrated prior to the trial, with the exception of offsets in the position transducers and oleo/tyre LVDTs. The ship trial follows on from a trial involving the same aircraft on a hydraulic tilt table at EDE proving ground, Monegeetta. Similarity of the trials should result in familiarity of trial technique and use of the instrumentation.

To ensure a variety of ship motion is generated, data will be collected at four different ship headings (ship travelling directly into swell, ship travelling 45 deg into swell, swell coming from beam, swell coming from astern). It may be necessary to turn stabilisers off if sufficient sea states are not encountered. Each data run (consisting of a single tie-down configuration with the ship speed and direction held steady) will be of five minutes duration. It is suggested that the ship hold speed and heading constant while runs at different tie-down configurations are performed. On the Tuesday this should result in a total of about one hour at each of the four headings for tie-down chains, and a further hour for each of the four headings using webbing tie-downs (a total of 8 hours). On the Wednesday the times should be significantly reduced. In addition, time needs to be allowed periodically to transfer data and check data quality.

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* *The term "Seahawk" refers here to the Australian version known as the S-70B-2.*

Tuesday is seen as the main part of the trial and should take place in open water. The RSD probe will be in the RAST track for all measurements. Reasonable ship motion is desired though if greater than sea state 3 is encountered, the 90 degree wave front direction should be approached with caution due to the possibility of excessive tie-down loads. Tie-down loads in the four cables will be continuously monitored to ensure they do not exceed the 10000 lbf and 5000 lbf limits for chains and nylon lashings respectively as required in Ref A. If at any time these limits are approached, the slack safety chains fitted as a safety measure are to be tightened.

During Wednesday morning, the ship should move to calmer waters (eg in the Jervis Bay area) where the RSD probe can be disengaged and some of the tie-down configurations from Monday repeated. All measurements should be completed by Wednesday lunchtime and the RSD probe reengaged. Should the RSD probe fail to engage, the ship can anchor in Jervis Bay and the helicopter be traversed out of the hangar manually.

It is suggested that the ship motion be established at the start of the trial for each of the four required headings with stabilisers on and off while the helicopter is tied down in the long term configuration. This will enable the trial plan to be modified if the ship pitch or roll angles look like exceeding the short term tie-down limits for Seahawk on FFG-7 ($\pm 10^{\circ}$ roll, $\pm 3^{\circ}$ pitch).

PRE TRIAL (SUNDAY 24 OCTOBER 1993 & MONDAY 25 OCTOBER 1993)

1. Aircraft arrives having already been weighed in a folded configuration to determine gross weight and cg position. Adjustments can be made for fuel used since weighing. All oleo and tyre pressures to be checked and adjusted as required prior to flying to ship.
2. Fit all instrumentation to helicopter and ship. Aim to attach the three horizontal position transducers "out of harm's way" so they are not damaged during tie-down configuration changes. Synchronise aircraft and ship computers.
3. Perform test run of instrumentation and determine offsets in position transducers and tyre/oleo LVDTs. Record helicopter position in hangar.
4. Tie helicopter down with four chains (short term lashing procedure). Record chain length and mark length on chain when at normal* tension. Mark several lines either side of this mark (in 1 cm gradations) to enable easy determining of chain length while at sea.
5. Tie helicopter down with four MC-1 webbing cables (short term lashing procedure). Record cable length and mark length on cable when at *normal* tension. Mark several lines either side of this mark (in 1 cm gradations) to enable easy determining of cable length while at sea.

TRIAL

The sequence outlined below is flexible and may well change depending on circumstances.

TUESDAY 26 OCTOBER 1993

RSD engaged in RAST track, Brakes off unless specified

CHAINS

NORMAL TENSION

All chains below to be at *normal* tie-down tension (additional slack safety chains to be used where required).

6a. Four tie-down chains to fuselage tie-down points (short term lashing procedure).

6b. Repeat of 6a with brakes ON.

* The *normal* tie-down condition is where the tie-down hook cannot be quite removed from the eye. This equates to a condition where about 3 cm of slack exists in the chain. This is the methodology currently used by the flight deck training team at RANAS Nowra. However, no written guidance was able to be provided.

7. Two tie-down chains to fuselage tie-down points (front two of short term lashing procedure).

8. No tie-down cables.

INCREASED TENSION

Reduce length of all chains below by 2 inches (or as appropriate) from value determined at 4 above (additional slack safety chains to be used where required).

9. Four tie-down chains to fuselage tie-down points (short term lashing procedure).

10. Two tie-down chains to fuselage tie-down points (front two of short term lashing procedure).

REDUCED TENSION

Increase length of all chains below by 2 inches (or as appropriate) from value determined at 4 above (additional slack safety chains to be used where required).

11. Four tie-down chains to fuselage tie-down points (short term lashing procedure).

12. Two tie-down chains to fuselage tie-down points (front two of short term lashing procedure).

MC-1 WEBBING CABLES

NORMAL TENSION

All cables below to be at *normal* tie-down tension (additional slack safety chains to be used where required).

13a. Four MC-1 webbing cables to fuselage tie-down points (short term lashing procedure).

13b. Repeat of 13a with brakes ON.

14. Two MC-1 webbing cables to fuselage tie-down points (front two of short term lashing procedure).

INCREASED TENSION

Reduce length of all cables below by 2 inches (or as appropriate) from value determined at 5 above (additional slack safety chains to be used where required).

15. Four MC-1 webbing cables to fuselage tie-down points (short term lashing procedure).

16. Two MC-1 webbing cables to fuselage tie-down points (front two of short term lashing procedure).

REDUCED TENSION

Increase length of all cables below by 2 inches (or as appropriate) from value determined at 5 above (additional slack safety chains to be used where required).

17. Four MC-1 webbing cables to fuselage tie-down points (short term lashing procedure).

18. Two MC-1 webbing cables to fuselage tie-down points (front two of short term lashing procedure).

ADDITIONAL DESIRABLE CONFIGURATIONS IN ORDER OF PRIORITY

19. Four tie-down cables to fuselage tie-down points (short term lashing procedure) where each cable comprises two MC-1 webbing cables in parallel. Normal tension.

20a. Two tie-down chains to fuselage tie-down points (rear two of short term lashing procedure). Normal tension.

20b. Two MC-1 webbing cables to fuselage tie-down points (rear two of short term lashing procedure). Normal tension.

20c. Repeat of 9, 11, 15, and 17 with brakes ON.

WEDNESDAY 27 OCTOBER 1993

RSD disengaged, Brakes off unless specified.

NORMAL TENSION CABLES

All cables below to be at *normal* tie-down tension (additional slack safety chains to be used where required).

21a. Four tie-down chains to fuselage tie-down points (short term lashing procedure).

21b. Repeat of 21a with brakes ON.

22. No tie-down cables.

23a. Four MC-1 webbing cables to fuselage tie-down points (short term lashing procedure).

23b. Repeat of 23a with brakes ON.

INCREASED TENSION CABLES

Reduce length of all cables below by 2 inches (or as appropriate) from value determined at 4 or 5 above (additional slack safety chains to be used where required).

24. Four tie-down chains to fuselage tie-down points (short term lashing procedure).

25. Four MC-1 webbing cables to fuselage tie-down points (short term lashing procedure).

REDUCED TENSION CABLES

Increase length of all cables below by 2 inches (or as appropriate) from value determined at 4 or 5 above (additional slack safety chains to be used where required).

26. Four tie-down chains to fuselage tie-down points (short term lashing procedure).

27. Four MC-1 webbing cables to fuselage tie-down points (short term lashing procedure).

ADDITIONAL DESIRABLE CONFIGURATIONS IN ORDER OF PRIORITY

28. Four tie-down cables to fuselage tie-down points (short term lashing procedure) where each cable comprises two MC-1 webbing cables in parallel. Normal tension.

29. Two tie-down chains to fuselage tie-down points (front two of short term lashing procedure). Normal tension.

30. Two MC-1 webbing cables to fuselage tie-down points (front two of short term lashing procedure). Normal tension.

31. Repeat of 24, 25, 26, and 27 with brakes ON.

Annex A to Appendix B - Channels Required

Aircraft

Variable	Number of Channels	Additional Information
Pitch Attitude Roll Attitude Yaw Attitude Pitch Rate Roll Rate Yaw Rate	1 2 3 4 5 6	Tap off Aircraft (as Planned during Seahawk/FFG-7 FOCFT)
Lateral Acceleration Longitudinal Acceleration Vertical Acceleration	7 8 9	Tap off Aircraft or Use Independent Accelerometers
Port Oleo LVDT Stbd Oleo LVDT Tail Oleo LVDT Port Tyre LVDT Stbd Tyre LVDT Tail Tyre LVDT	10 11 12 13 14 15	Previously Instrumented
Helicopter Position Relative to a Datum* Tie-Down Cable Tensions†	16,17,18,19 20,21,22,23	Previously Instrumented

Ship

Variable	Number of Channels	Additional Information
Roll Attitude (Vert Gyro) Roll Rate Lateral Acceleration Vertical Acceleration Pitch Attitude (Vert Gyro) Pitch Rate Yaw Rate Longitudinal Acceleration	1 2 3 4 5 6 7 8	Motion Platform
Speed Heading		Ship Synchro Channels

- All channels sampled at 40 Hz except load cells which are sampled at 80 Hz.

* 3 spring loaded rotary pots with cables, each capable of 1 metre extension, will be used to connect the aircraft fuselage to hangar walls. They will record longitudinal and lateral helicopter position with redundancy. A 4th rotary pot, capable of 0.5 metre extension, will be mounted vertically between helicopter fuselage and deck.

† Up to four strain-gauged links will be used, one for each tie-down cable. Maximum load recordable is 2000 kgf.

APPENDIX C
TEST CONDITIONS ACHIEVED FOR S-70B-2 ON TILT TABLE

Test points were obtained for three conditions:

(i) Static raising of the table was carried out with no loading on any tie-down lashings (Table C1). This was performed so that the vertical cg of the helicopter could be determined, and also, together with lateral tyre deflections that were recorded, so that lateral tyre stiffness coefficients could be deduced.

(ii) Dynamic raising of the table was carried out with TD-1A chains used as tie-down lashings (Table C2).

(iii) Dynamic raising of the table was carried out with MC-1 webbing used as tie-down lashings (Table C3). Both single and double thickness webbing was used so that different extendibility of lashings could be examined. Because MC-1 webbing is non-standard for the S-70B-2, slack TD-1A chains were used as safety lashings.

Results followed the trial plan except for a few modifications discussed in Section 2.2.

TABLE C1
Static Raising of Table (No Loaded Lashings)

Trial Plan Sequence Number	Table Angle (deg)	File No.	
		Aircraft	Table
12	0	A1	T1
12	2	A2	T2
12	4	A3	T3
12	6	A4	T4
12	8	A5	T5
12	10	A6	T6

TABLE C2
Dynamic Raising of Table (TD-1A Chains)

Trial Plan Sequence Number	Max Table Angle (deg)	No. Chains /Location	Tension	Brake Status	File No.		Comments
					Aircraft	Table	
12i	6	0	-	ON	A7	T7	Table "searched" at low angle - not very satisfactory
13	6	0	-	ON	A8	T8	Repeatability Check
extra	0	0	-		A8r	-	A8r records the settling of helicopter as brakes are released from A8/T8
12ii	12	0	-	OFF	A9	T9	
14i	12	2	Normal	OFF	A10	T10	
14ii*	15	2	Normal	OFF	A11	T11	
15	15	2	Normal	OFF	A12	T12	Repeat of A11/T11
15	15	2	Normal	OFF	A23	T23	Repeat of A11/T11
14ii*	15	2	Normal	ON	A24	T24	Configuration as A11/T11 but with brakes ON. Brakes released after 2 full table cycles and subsequent settling of helicopter all recorded
17i	12	2	Reduced	OFF	A13	T13	
17ii*	15	2	Reduced	OFF	A14	T14	
Extra	15	2	Reduced	OFF	A15	T15	Table oscillated between 12 deg and 15 deg
16i	12	2	Increased	OFF	A16	T16	
16ii*	15	2	Increased	OFF	A17	T17	
16ii*	15	2	Increased	OFF	A18	T18	Repeat of A17/T17 but with brief pause between first and second table cycles
18ii	12	1, Fwd	Normal	OFF	A19	T19	
18i	6	1, Fwd	Normal	OFF	A20	T20	
19ii*	10	1, Aft	Normal	OFF	A21	T21	
19i	6	1, Aft	Normal	OFF	A22	T22	

* Configuration as on Trial Plan except a different maximum tilt table angle was selected.

TABLE C3
Dynamic Raising of Table (MC-1 Webbing)

Trial Plan Sequence Number	Table Angle (deg)	No. Lashings /Location	Tension	Brake Status	File No.		Comments
					Aircraft	Table	
20a (14ii)*	15	2	Normal	OFF	A25	T25	
20a (14i)	12	2	Normal	OFF	A26	T26	T26 ended ~5 s after A26
20a (16i)	12	2	Increased	OFF	A27	T27	
20a (16ii)*	15	2	Increased	OFF	A28	T28	
20a (17i)	12	2	Reduced	OFF	A29	T29	Brief pause between first and second table cycles
20a (17i)	12	2	Reduced	OFF	A30	T30	Repeat of A29/T29 without pause between cycles
20a (17i)*	6	2	Reduced	OFF	A31	T31	
20b (16ii)*	15	2 Double	Increased	OFF	A32	T32	
20b (16i)	12	2 Double	Increased	OFF	A33	T33	
20b (16i)	12	2 Double	Increased	OFF	A39	T39	Repeat of A33/T33
20b (16i)	12	2 Double	Increased	ON	A38	T38	Configuration as A33/T33 but with brakes ON. Brakes released after 2 full table cycles and subsequent settling of helicopter all recorded
20b (14ii)*	15	2 Double	Normal	OFF	A34	T34	
20b (14i)	12	2 Double	Normal	OFF	A35	T35	
20b (14i)	12	2 Double	Normal	OFF	A36	T36	Repeat of A35/T35
20b (14i)	12	2 Double	Normal	ON	A37	T37	Configuration as A35/T35 but with brakes ON. Brakes released after 2 full table cycles and subsequent settling of helicopter all recorded. T37 started ~5 s after A37 but still recorded 2 full table cycles

* Configuration as on Trial Plan except a different maximum tilt table angle was selected.

APPENDIX D
TEST CONDITIONS ACHIEVED FOR S-70B-2 ON HMAS MELBOURNE

Test points were obtained for both RSD connected and disconnected. Chains, single thickness webbing, and double thickness webbing were used as tie-down lashings. Observations revealed that the MC-1 webbing lashings suffered from significant slippage (Table D3) so they were replaced by CGU-1/B webbing lashings in order that repeatable results could be obtained which would be suitable for post-trial analysis. Ship heading was varied to provide for different ship motion. The test conditions are grouped together into common ship motion and lashing types. The sea state is shown for each set of results, and whether ship roll or pitch motion was dominant, or whether both modes were significant.

Results followed the trial plan (Appendix B) except for a few modifications discussed in Section 2.3.

TABLE D1
RSD Connected, Helicopter Tied Down with TD-1A Chains, Sea State 2, Ship Roll and Pitch Motion Significant

Trial Plan Sequence Number	No. Chains /Location	Tension	Brake Status	File No.		Comments
				Aircraft	Ship	
6a	4	Normal	OFF	H1	S1	
6b	4	Normal	ON	H2	S2	
7	2 Fwd	Normal	OFF	H3	S3	
20a	2 Aft	Normal	OFF	H4	S4	
9	4	Increased	OFF	H5	S5	
20c (9)	4	Increased	ON	H6	S6	
10	2 Fwd	Increased	OFF	H7	S7	
11	4	Reduced	OFF	H8	S8	
20c (11)	4	Reduced	ON	H9	S9	
12	2 Fwd	Reduced	OFF	H10	S10	
8	0	-	OFF	H11	S11	Non-instrumented fwd stbd safety chain went taut momentarily around 1-2 min
8†	0	-	ON	H12	S12	
Extra	8	Normal	OFF	H13	S13	All chains remained unloaded on port side. Intermediate tie-down scheme with 4 load cells on stbd side. Two stbd short-term chains at *normal* length from pre-trial measurements, other two stbd chain settings estimated by adjusting tension till felt *normal*. Unloaded length was not recorded

† Configuration as on Trial Plan except brakes were ON.

TABLE D2
RSD Connected, Helicopter Tied Down with TD-1A Chains, Sea State 3, Ship Roll Motion Dominant

Trial Plan Sequence Number	No. Chains /Location	Tension	Brake Status	File No.		Comments
				Aircraft	Ship	
6a	4	Normal	OFF	H16	S16	
6b	4	Normal	ON	H17	S17	
7	2 Fwd	Normal	OFF	H18	S18	High roll case
20a	2 Aft	Normal	OFF	H19	S19	Port fwd safety chain (no load cell) went momentarily taut (just) at around 2:50
9	4	Increased	OFF	H20	S20	
20c (9)	4	Increased	ON	H21	S21	
10	2 Fwd	Increased	OFF	H22	S22	H22 ended ~2 s after S22
11	4	Reduced	OFF	H23	S23	
20c (11)	4	Reduced	ON	H24	S24	
12	2 Fwd	Reduced	OFF	H25	S25	
8	0	-	OFF	H26	S26	
8†	0	-	ON	H27	S27	Possibly port fwd safety chain went taut near end of run, possibly stbd tyre LVDT went off deck-plate briefly
Extra	8	Normal	OFF	H14	S14	All chains on port side set at normal tension but no load cells. Intermediate tie-down scheme with load cells on stbd side. Two stbd short-term chains at *normal* length from pre-trial measurements, other two stbd chain settings estimated by adjusting tension till felt *normal*. Unloaded length was not recorded.
Extra	8	Normal	ON	H15	S15	Configuration as H14/S14

TABLE D3
RSD Connected, Helicopter Tied Down with MC-1 Webbing, Sea State 4, Ship Roll and Pitch Motion Significant

Trial Plan Sequence Number	No. Lashings /Location	Tension	Brake Status	File No.		Comments
				Aircraft	Ship	
13a	4	Normal	OFF	H28	S28	Helicopter able to roll significantly more with webbing than with chains. Port fwd safety chain went taut (just) at 3:45 after start
13a	4	Normal	OFF	H33	S33	Repeat of H28/S28 to see if MC-1 lashings slipped under normal tension as well as increased tension. They did. Runs with MC-1 lashings aborted from now on
13b	4	Normal	ON	H29	S29	
15	4	Increased	OFF	H30	S30	Oleos warming up due to excessive movement compared to chains
20c (15)	4	Increased	ON	H31	S31	Significant slippage of MC-1 lashings first noted. Reset prior to H32/S32
16	2 Fwd	Increased	OFF	H32	S32	Significant slippage of MC-1 lashings occurred

† Configuration as on Trial Plan except brakes were ON.

TABLE D4
RSD Connected, Helicopter Tied Down with CGU-1/B Webbing, Sea State 4, Ship Roll and Pitch Motion Significant

Trial Plan Sequence Number	No. Lashings /Location	Tension	Brake Status	File No.		Comments
				Aircraft	Ship	
13a	4	Normal	OFF	H34	S34	A check revealed no slippage of lashing
13b	4	Normal	ON	H35	S35	
15	4	Increased	OFF	H36	S36	
20c (15)	4	Increased	ON	H37	S37	
16	2 Fwd	Increased	OFF	H38	S38	
19[@]	2 Double	Increased	OFF	H39	S39	Two double thickness lashings on stbd side. Two reduced tension chains (i.e. 1.5 inch longer than *normal*) on port side

TABLE D5
RSD Connected, Helicopter Tied Down with CGU-1/B Webbing, Sea State 4, Ship Pitch Motion Dominant

Trial Plan Sequence Number	No. Lashings /Location	Tension	Brake Status	File No.		Comments
				Aircraft	Ship	
13a	4	Normal	OFF	H40	S40	
13b	4	Normal	ON	H41	S41	Port tyre LVDT may have jumped off and back on deck-plate. Would show up as a step
15	4	Increased	OFF	H42	S42	
20c (15)	4	Increased	ON	H43	S43	
16	2 Fwd	Increased	OFF	H44	S44	
19[@]	2 Double	Increased	OFF	H45	S45	Two double thickness lashings on port side. Safety chains taking no load on stbd side
19[@†]	2 Double	Increased	ON	H46	S46	As H45/S45. Ship recording started ~ 1 s late

TABLE D6
RSD Disconnected, Helicopter Tied Down with TD-1A Chains, Sea State 3, Ship Roll Motion Dominant

Trial Plan Sequence Number	No. Chains /Location	Tension	Brake Status	File No.		Comments
				Aircraft	Ship	
21a	4	Normal	OFF	H49	S49	
21b	4	Normal	ON	H50	S50	
24	4	Increased	OFF	H48	S48	Aircraft recording stopped ~15 s after ship
31 (24)	4	Increased	ON	H47	S47	Brakes came off momentarily - were applied a second time

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[@] Configuration as on Trial Plan except double thickness lashings were on one side only with no loaded lashings on other side. Also, lashings were set at taut tension not normal.

[†] Configuration as on Trial Plan except brakes were ON.

TABLE D7
RSD Disconnected, Helicopter Tied Down with CGU-1/B Webbing, Sea State 3, Ship Roll Motion Dominant

Trial Plan Sequence Number	No. Lashings /Location	Tension	Brake Status	File No.		Comments
				Aircraft	Ship	
28@†	2 Double	Increased	ON	H51	S51	Configuration as H39/S39
28@	2 Double	Increased	OFF	H52	S52	Configuration as H39/S39. Port fwd safety chain went taut at ~40 s and ~3:10

TABLE D8
RSD Disconnected, Helicopter Tied Down with TD-1A Chains, Sea State 3, Ship Roll and Pitch Motion Significant

Trial Plan Sequence Number	No. Chains /Location	Tension	Brake Status	File No.		Comments
				Aircraft	Ship	
21a	4	Normal	OFF	H53	S53	
21b	4	Normal	ON	H54	S54	
24	4	Increased	OFF	H55	S55	
31 (24)	4	Increased	ON	H56	S56	
26	4	Reduced	OFF	H58	S58	
31 (26)	4	Reduced	ON	H57	S57	

TABLE D9
RSD Disconnected, Helicopter Tied Down with CGU-1/B Webbing, Sea State 3, Ship Roll and Pitch Motion Significant

Trial Plan Sequence Number	No. Lashings /Location	Tension	Brake Status	File No.		Comments
				Aircraft	Ship	
25	4	Increased	OFF	H62	S62	Port safety chain went taut at ~15 s and ~3:45
31 (25)	4	Increased	ON	H61	S61	
28@†	2 Double	Increased	ON	H59	S59	Two double thickness lashings on port side. Two instrumented reduced tension chains (1.5 inch longer than *normal*) on stbd side
28@	2 Double	Increased	OFF	H60	S60	Configuration as H59/S59

@ Configuration as on Trial Plan except double thickness lashings were on one side only with no loaded lashings on other side. Also, lashings were set at taut tension not normal.

† Configuration as on Trial Plan except brakes were ON.

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AL 149 DEPARTMENT OF DEFENCE

PAGE CLASSIFICATION
UNCLASSIFIED

PRIVACY MARKING

DOCUMENT CONTROL DATA

1a. AR NUMBER	1b. ESTABLISHMENT NUMBER	2. DOCUMENT DATE	3. TASK NUMBER
AR-008-418	DSTO-TR-0132	JANUARY 1995	NAV 92/019

4. TITLE	5. SECURITY CLASSIFICATION	6. NO. PAGES
TIE-DOWN TRIALS INVOLVING A SIKORSKY S-70B-2 HELICOPTER	(PLACE APPROPRIATE CLASSIFICATION IN BOX(S) IE. SECRET (S), CONF. (C) RESTRICTED (R), LIMITED (L), UNCLASSIFIED (U)).	38
	DOCUMENT: U / TITLE: U / ABSTRACT: U	7. NO. REFS. 2

8. AUTHOR(S)	9. DOWNGRADING/DELIMITING INSTRUCTIONS
J. BLACKWELL	Not applicable.

10. CORPORATE AUTHOR AND ADDRESS	11. OFFICE/POSITION RESPONSIBLE FOR:
AERONAUTICAL AND MARITIME RESEARCH LABORATORY AIR OPERATIONS DIVISION PO BOX 4331 MELBOURNE VIC 3001 AUSTRALIA	NAVY SPONSOR - SECURITY - DOWNGRADING CAOD APPROVAL

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14. DESCRIPTORS		15. DISCAT SUBJECT CATEGORIES
S-70B helicopters	Oliver Hazard Perry class frigates	
Stowage (onboard equipment)	Helicopter carriers	

16. ABSTRACT

Two tie-down trials involving a Sikorsky S-70B-2 helicopter are outlined. The first was land-based and utilised a hydraulic tilt table. The second took place on board an FFG-7 frigate. The trials are part of a DSTO investigation aimed at improving the tie-down procedures of S-70B-2 helicopters when operating from ships. A preliminary analysis of the data is presented and indicates that the type of lashing used to secure the helicopter can have a significant effect on the loads transmitted to the fuselage as well as affecting the relative motion of the aircraft. The effect of aircraft brakes on or off was examined and found to result in noticeable differences to the aircraft behaviour. During the ship trial, one type of tie-down lashing was observed to suffer from significant slippage through its locking mechanism.

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16. ABSTRACT (CONT).

17. IMPRINT

AERONAUTICAL AND MARITIME RESEARCH LABORATORY, MELBOURNE

18. DOCUMENT SERIES AND NUMBER	19. WA NUMBER	20. TYPE OF REPORT AND PERIOD COVERED
DSTO Technical Report 0132	76000B	

21. COMPUTER PROGRAMS USED

22. ESTABLISHMENT FILE REF.(S)

M1/9/25

23. ADDITIONAL INFORMATION (AS REQUIRED)